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POTENTIAL CONTAMINATION OF THE HYDROLOGIC ENVIRONMENT FROM THE PESTICIDE WASTE DUMP IN HARDEMAN COUNTY, TENNESSEE

D. R. Rima, et al

Geological Survey
Washington, D. C.

August 1967

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by

D. R. Rima, E. Brown, D. F. Goerlitz, and L. M. Law

Water Resources Division

Administrative report to

THE FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

August 1967

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THE PROBLEM

In October 1964, The Velsicol Chemical Corporation began disposing of toxic waste materials from the manufacture of certain chlorinated hydrocarbons (pesticides) by shallow burial at a site in northeastern Hardeman County, Tennessee. Upon learning of this activity, public health officials became gravely concerned about the potential health hazard owing to the toxic nature of the wastes. Particular concern was expressed by health officials over the possibility that these toxic wastes might contaminate, and thus render useless, local and contiguous water supplies. The Company, on the other hand, expressed the opinion that shallow burial of toxic wastes was a time-honored practice and it did not pose any real or immediate hazard to public health.

In order to resolve this question, the Federal Water Pollution Control Administration requested the U.S. Geological Survey to investigate the disposal site and determine the susceptibility of contamination of the hydrologic environment resulting from the shallow burial of pesticide wastes. Concern about contamination in the hydrologic environment centered on four pertinent questions. Answers to these questions are summarized in the conclusions which follow.

CONCLUSIONS

1. Is there now contamination of the environment from disposal pits; if so, what portion is now contaminated and to what degree?

The analytical results show clearly that the shallow burial of pesticide wastes in Hardeman County has contaminated portions of both the surface and subsurface environment at the disposal site. Evidence of contamination of the surface environment was found in samples of the surface soil at the disposal site, in samples of sediment washoff from the disposal site, and in samples of the bedload in Pugh Creek as far as 1 1/2 miles downstream from the site. On the other hand, the water portion of samples from Pugh Creek did not contain any detectable amounts of chlorinated hydrocarbons.

The degree of contamination of the surface environment is indicated by the following table which compares the analysis of plant waste with the maximum reported concentrations of pesticide materials in samples from various sampling sites.

Maximum value reported in analytical results
of soil and sediment samples
(Results in micrograms per kilogram)

Constituents	Plant Wastes	Sediment washoff	Pugh Creek bedload
Heptachlor	2.0×10^8	1600	3.2
Dieldrin	1.2×10^6	250	0.24
Endrin	4.5×10^6	73	0.10
Heptachlor epoxide	3.9×10^4	6.5	0.0

It is obvious from the foregoing table that attenuation accompanies the overland movement of the reported contaminants.

In the subsurface the buried wastes have produced a zone or enclave of contamination directly beneath and peripheral to the disposal pits. Laterally, the limits of the enclave appear to be confined within a distance of 25 feet from the outermost margins of the disposal pits. The depth of the enclave, however, extends nearly to the water table which is about 90 feet beneath the land surface.

Within the contaminated enclave the degree of contamination is greatest in the formation in which the wastes are deposited where values of up to 6 million µg/kg (micrograms per kilogram) of organic chlorine were found. It is least in the outermost fringe where a concentration of 5 µg/kg of organic chlorine was recognized as a positive indication of contamination. Attenuation of the contamination with depth was clearly evident in the analytical results.

II. What is the potential contamination hazard to local groundwater from percolation?

The vertical movement of the pesticide contaminants from the disposal pits poses a contamination hazard for 2 of the 3 ground-water bodies that occur beneath the disposal pits. The shallowest groundwater body (a perched water zone) has already become contaminated as evidenced by analytical results of water samples from shallow wells marginal to the disposal pits (table 1). The portion of this zone, that is or can be contaminated, however, is limited in areal extent to about 40 acres. Moreover, it is not used as a source of water supply because it holds no water during dry seasons.

In addition to the perched water zone, a substantial portion of the local water-table aquifer, the principal source of local domestic water supplies, is exposed to the hazard of contamination from the pesticide waste disposal pits. The exposed portion has an areal extent of about 150 acres and includes the segments of the aquifer that underlie and receive recharge from the portion of the perched water zone that is susceptible to contamination, and the draws which carry contaminated wash-off from the disposal site. In addition, it includes the part of the water-table aquifer that is down gradient from the sources of potentially contaminated recharge.

There is little likelihood that ground water in the artesian aquifer will ever be exposed to contamination from the disposal pits because this aquifer does not receive recharge from any of the aforementioned contaminated or potentially contaminated portions of the environment.

III. What is the potential contamination hazard to contiguous groundwaters?

The contaminants that are entrained in the flow systems of the perched water zone and the water-table aquifer will move laterally toward the discharging boundaries of these ground-water bodies. The contaminants entrained in the perched water zone will move toward the discharging boundaries that are located within the surface ravines draining the disposal pits. The maximum rate of movement in the zone under prevailing hydraulic gradients is calculated to be about 2 feet per day. Hence, the entrained contaminants could reappear at the land surface in as little as 100 or as many as 1200 days after entry into the perched zone.

The contaminants entrained in the flow system of the water-table aquifer will migrate northeasterly following the slope of the prevailing water-table gradient. Eventually, these contaminants will be discharged into Pugh Creek. The minimum time that would be required for the entrained contaminants to reach the Creek is calculated to be 5 years.

Withdrawals from wells could conceivably induce the contaminants entrained in the flow system of the water-table aquifer to move outside the portion of the aquifer that is in danger of contamination. Assuming the withdrawals are made at the maximum yield of the aquifer (40 gallons per minute) and continued for an indefinite period of time, wells on the western side of the disposal site (upgradient) would need to be located within 900 feet of the points of entry of contaminants into the aquifer in order for contaminated water to reach the point of withdrawal. Likewise, wells north or south of the disposal site (perpendicular to the prevailing gradient) would need to be located within 1500 feet of the potentially contaminated portion of the aquifer. If pumping is intermittent or at a lower rate than the maximum yield of the aquifer, the distance that potentially contaminated water can be diverted is, of course, commensurately less. Wells outside the limits indicated are in no potential danger of contamination by subsurface movement of contaminants.

IV. Are there other hydrologic factors related to contamination hazard that have become evident directly or indirectly from this study, such as topography, drainage, or runoff intensity?

The contaminants appear to have a greater affinity for clayey earth materials than for water. It is, therefore, doubtful that the contaminants will move as rapidly in the subsurface as ground water is able to move. It is also unlikely that contaminated particles of sediment in the draws and in Pugh Creek will be relieved of contaminants merely by association with water.

Certain features of the environment of the disposal site serve to delay the contamination hazard to the hydrologic system. These are:

1. The 90-foot depth to the water table
2. The presence of 3 beds of lowly permeable clayey material in the zone of aeration
3. The prevailing easterly water-table gradient
4. The remoteness of the disposal site from local inhabitants.

Although not specifically questioned, it is pertinent that some of the pesticide waste is very acidic (pH 1-2). Some of the contaminated core samples were also acidic (pH 3.45). The presence of this acidic condition might increase or decrease the vertical permeability of the earth materials in the subsurface, and thereby affect the rate of vertical movement of contaminants through the zone of aeration.

INTRODUCTION

As evidenced by the foregoing questions, the scope of the investigation included the total field of movement of the pesticide waste materials within the hydrologic system. Considered were such hydrologic factors as surface runoff, sediment transport, hydraulics of ground-water movement, leaching and the interaction of the wastes with the environment. During the investigation, approximately 110 samples of surface runoff and washoff were collected for pesticide analysis from a network of strategic sampling sites. In addition, about 200 core samples and 10 samples of ground water were obtained for analysis from the subsurface beneath and adjacent to the disposal site.

Insofar as the analytical work was concerned, the scope of the investigation was originally limited to the four chlorinated hydrocarbons; dieldrin, endrin, heptachlor, and heptachlor epoxide because these compounds were considered to be characteristic of the buried waste materials. For these 4 pesticides the lower limits of measurement as reported herein are 0.01 micrograms per liter for water samples and 0.1 micrograms per kilogram for sediment and core samples. Later, to provide a more complete description of the waste material in core samples, total organic chlorine was determined to a lower limit of 0.5 micrograms per kilogram.

The investigation did not include an evaluation of the implications of the hydrologic findings upon the dangers to public health and welfare because such an evaluation is clearly the prerogative of health and pollution control agencies.

Description of the Disposal Site

The disposal site is located on a 300-acre farm in northeastern Hardeman County, Tennessee. It is about 1 1/2 miles northwest of the intersection of State Highways 18 and 100. (See figure 1). The site lies within the drainage area of Pugh Creek, a northward-flowing tributary to Clover Creek, and is situated near the drainage divide along the western side of Pugh Creek Valley. Hence, the general direction of surface drainage from the site is toward the east.

Topographically, the disposal site is situated on an upland remnant of a maturely dissected, fluvial terrace. The general level of the upland is about 80 to 100 feet above the flood plain of Pugh Creek. Between the flood plain and the uplands, the land surface is marked by fairly steep-sided gullies and ravines.

The disposal site is underlain by a sequence of nearly horizontal strata that are composed of deposits of sand, silt, and clay. To a depth of about 100 feet these strata consist predominantly of sand deposits interbedded with a few thin deposits of silt and clay, but below a depth of 100 feet beds of clay are predominant. The sequence and general character of the uppermost 250 feet of strata are shown diagrammatically by the geologic cross-section in figure 2. The beds of sand are numbered sequentially from the surface downward to facilitate identification in the text.

Sand number 1 is a yellowish-orange to reddish-brown, fine- to very coarse-grained, poorly sorted quartz sand. It is weakly stratified and contains small pockets and lenses of light gray to reddish-brown silt, small pieces of ironstone, and scattered pebbles of quartzite. Except for iron oxide which occurs as grain coatings and cementing material, this deposit is mineralogically almost pure silica (SiO_2).

The bed of clayey material that underlies sand number 1 is a remnant of an ancient soil that developed beneath the surface of erosion which existed prior to the deposition of sand number 1. It contains a nearly continuous bed of ironstone (iron-oxide cemented siltstone or sandstone) along its upper surface.

Sands 2, 3, and 4 are light gray to yellowish, fine- to very coarse-grained, poorly to well sorted, quartz sand. These deposits are distinctly stratified with thin (generally less than one foot) alternating beds or lenses of sand that differ in grain size and sorting. Some of the individual beds or lenses of sand in sand number 4, are composed of very coarse, well sorted quartz sand.

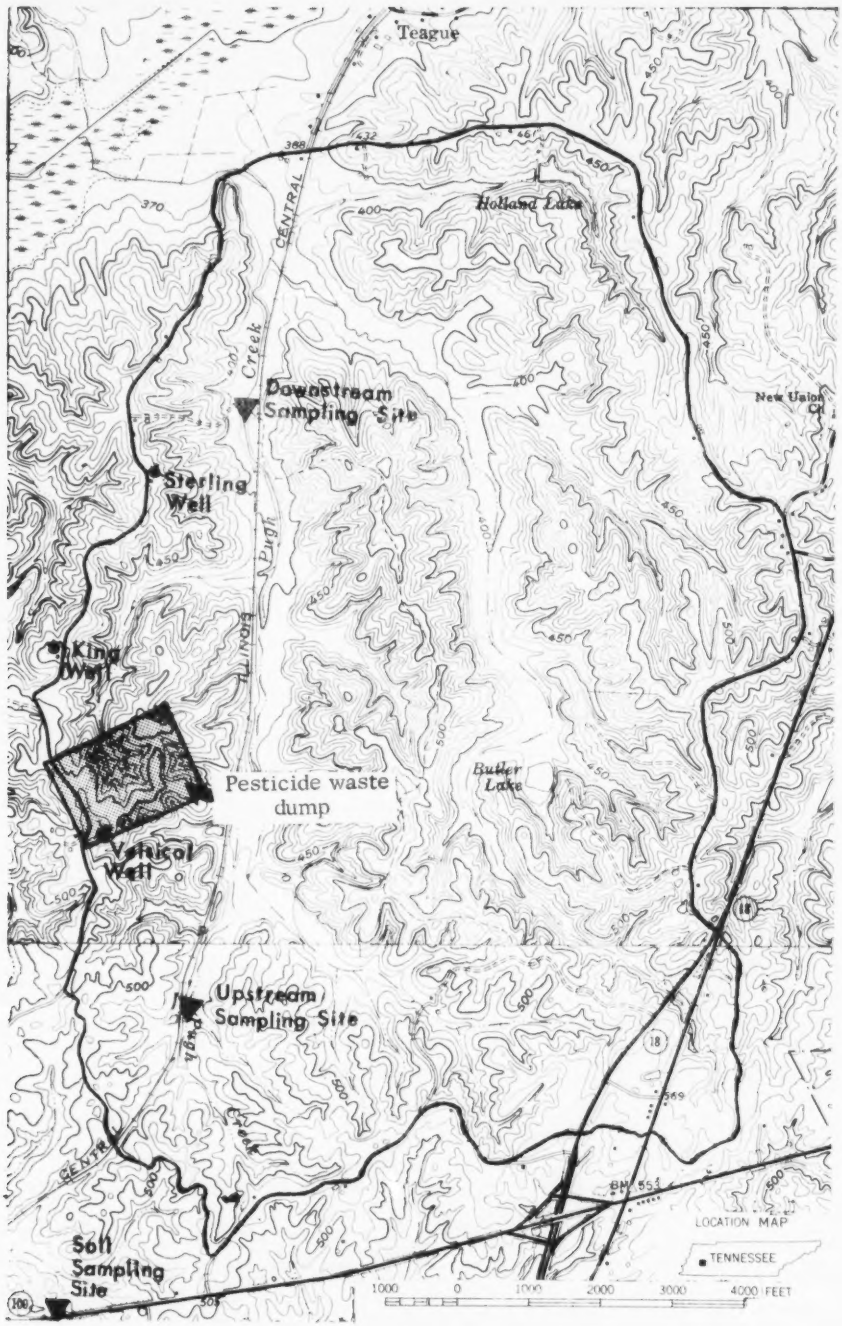

Figure 1--Map of Pugh Creek drainage basin

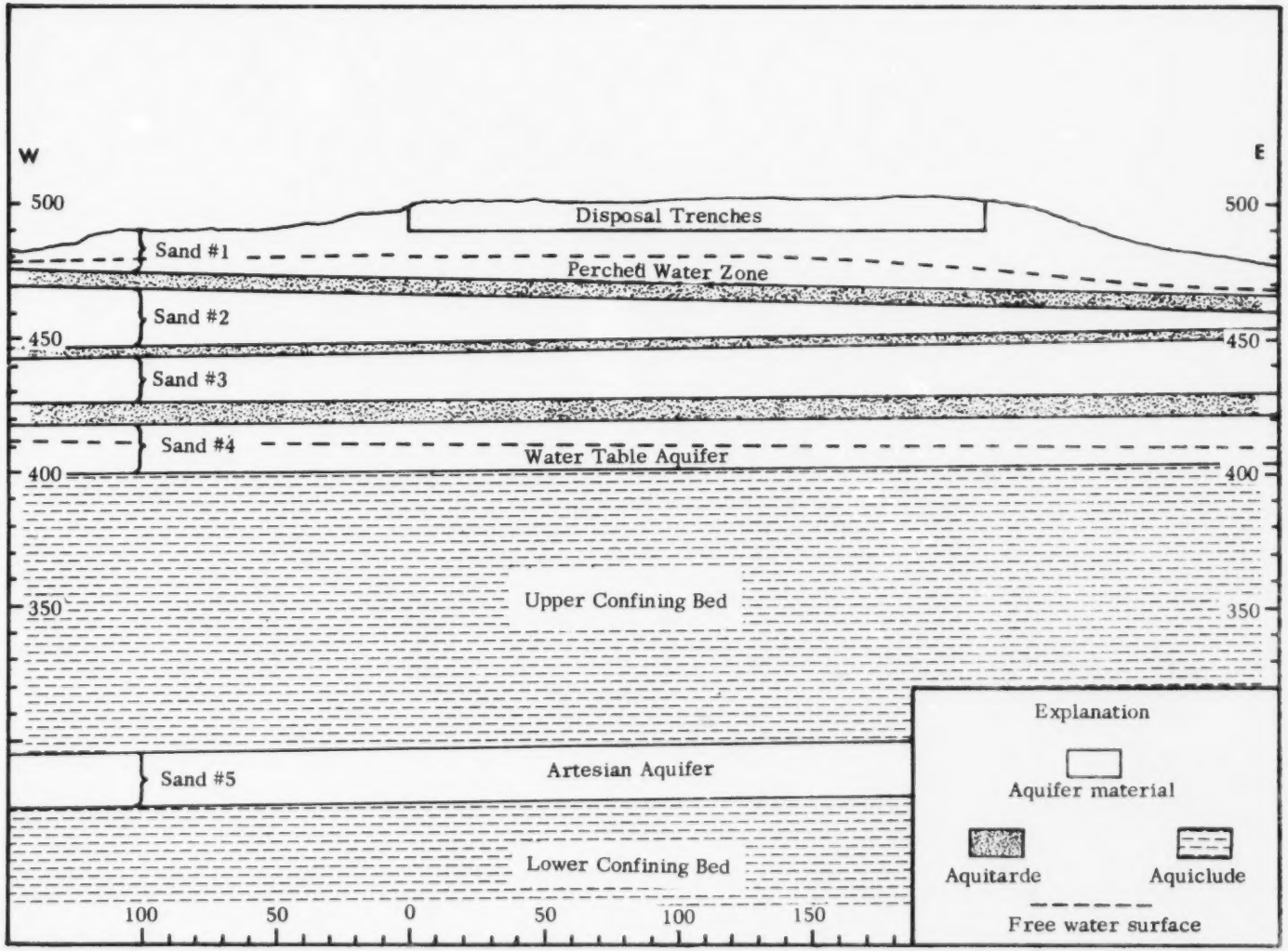

Figure 2--Geologic cross-section of disposal site.

The 2 beds of clayey material that separate sand number 3 from sands numbered 2 and 4 (fig. 2) consist of irregular-shaped lenses and circular, oblate, and tabular masses of kaolinitic clay in a quartzose sand matrix.

The upper and lower confining beds are composed of gray- to bluish-gray, laminated- to thick-bedded and blocky silt and clay. These beds contain carbonaceous plant remains, siderite concretions, and ferruginous siltstones.

Sand number 5 is a light gray- to yellowish-gray, medium- to very coarse-grained, poorly sorted quartz sand.

The uppermost 250 feet of strata beneath the disposal site embraces 3 distinct bodies of ground water; a perched water zone, a water-table aquifer, and an artesian aquifer (fig. 2). The perched water zone occurs in the basal part of the uppermost sand (sand No. 1) immediately above the less permeable clayey stratum that directly underlies the sand. Water or any other liquid that enters the subsurface and migrates downward under the influence of gravity is prone to accumulate at this horizon because the clayey material on which the sand rests has substantially less permeability than the sand. The perched water zone expands during the winter and spring seasons owing to the abundance of recharge and contracts or dissipates during the summer and fall seasons when recharge is minimal. Doubtless, some water escapes from the perched zone by movement downward through the clayey substratum, and some escapes by lateral migration to surface seeps along the slopes that border the disposal site.

The water-table aquifer occurs at a depth of about 90 feet below the surface of the disposal site and 60 feet below the base of the perched water zone. It occupies a 10-foot interval at the base of sand No. 4 (fig. 2). Measurements of water levels in observation wells at the disposal site indicate that the water table slopes generally toward the east. The water-table aquifer is recharged locally by leakage from the perched water zone through the thin clayey strata that occur between the perched water zone and the water table. It is also recharged by the infiltration of rainfall in those areas where the perched water zone is absent. Discharge from the water-table aquifer takes place through seeps and springs which are in evidence wherever the land surface intersects the water table. The point of discharge from this aquifer nearest the disposal site is located in the channel of Pugh Creek a few hundred feet upstream from the intersection of the channel and the 400-foot contour (fig. 1). Downstream from this point, Pugh Creek is a perennial stream deriving its dry-weather flow from the water-table aquifer.

The artesian aquifer occurs at a depth of 200 to 225 feet beneath the disposal site. It is separated from the water-table aquifer by a bed of silt and clay that is about 100 feet thick. This intervening bed is an upper confining bed to the artesian aquifer. Even though the head in

the artesian aquifer as measured in the Velsicol well is less than that in the water-table aquifer as measured in well W-1 (fig. 3), the thickness and character of the upper confining bed preclude any direct hydraulic connection between the water table and artesian aquifers. Hence, recharge to and discharge from the artesian aquifer are believed to take place mainly in the outcrop area of the aquifer which is located several miles east from the disposal site. Some additional discharge from the artesian aquifer is occasioned by withdrawals from wells that tap the aquifer such as the Velsicol well near the entrance to the disposal site.

Character of the Wastes and Method of Disposal

The bulk of the waste materials that are being transported to Hardeman County for disposal consist of still bottoms and dry spent catalyst and reactor solids from the manufacture of endrin, heptachlor, and heptachlor epoxide. Included with these wastes is a minor amount of miscellaneous trash consisting of contaminated earth, laboratory wastes, and conventional land-fill materials.

Although the chemical content of the wastes is not determined prior to burial, it is obvious that the compounds contained therein include, in addition to the 3 manufactured compounds, several related compounds that are either intermediates or by-products in the manufacturing process. Samples of the liquid and solid wastes provided by the manufacturer were analyzed by electron capture gas chromatography and found to contain 1200 to 1500 mg/kg (milligram per kilogram) of dieldrin, 4500 to 5900 mg/kg of endrin, 200,000 mg/kg of heptachlor and 39 mg/kg of heptachlor epoxide (see table 6). According to the manufacturer, some of the related compounds that can be expected to occur in the wastes are isodrin, aldrin, chlordene, hexachlorocyclopentadiene, and hexachlorobicycloheptadiene. The relative quantities of these compounds in the wastes, however, are not known.

As the waste materials are generated at the plant, they are placed in used 55-gallon steel drums and fiber cartons. The drums containing liquid wastes are closed with lids to prevent spillage during shipment. The wastes are hauled to the disposal site in large dump trucks; usually several truckloads are taken to the disposal site each day. Upon arrival at the site the wastes, including the containers, are dumped into elongated pits or trenches which have been excavated to a depth of about 12 feet and a width of about 15 feet. In the process of dumping, many of the containers are crushed or otherwise ruptured and their contents released within the trenches. After each dumping the wastes are covered with a minimum of 3 feet of earth material.

As of the writing of this report (June 1967), the trenches in which pesticide wastes have been buried are grouped into 3 adjoining areas or plots as shown on figure 3. Within each plot the trenches are spaced from 5 to 12 feet apart. Plot number 1 was used for dumping from October 1964 until May 1966, and Plot number 2 was used from April 1966 until May 1967. Plot number 3 has been in use since mid-March 1967.

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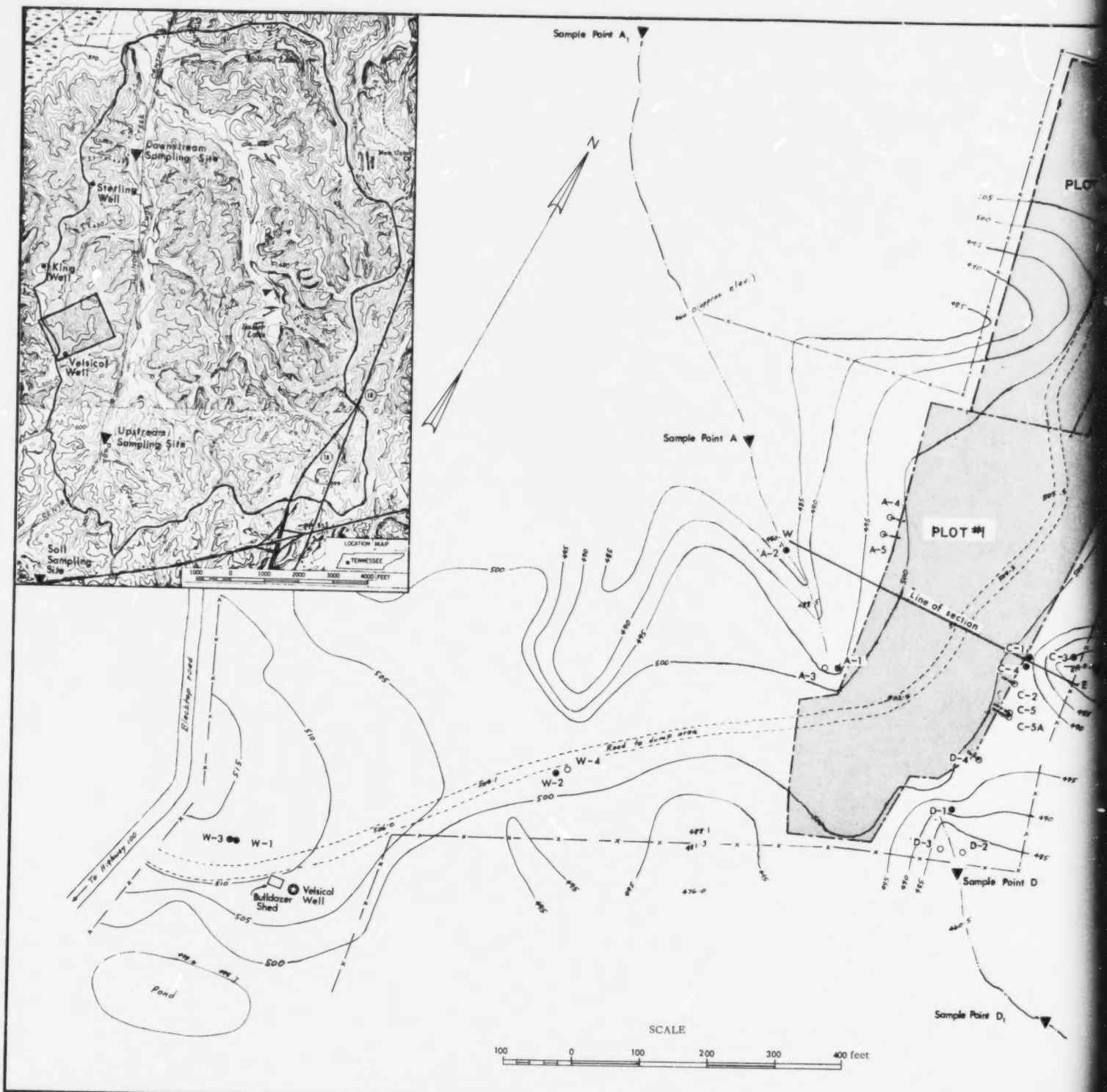

Figure 3--Map of the dump site showing the locations of the waste burial plots and the sampling sites and test

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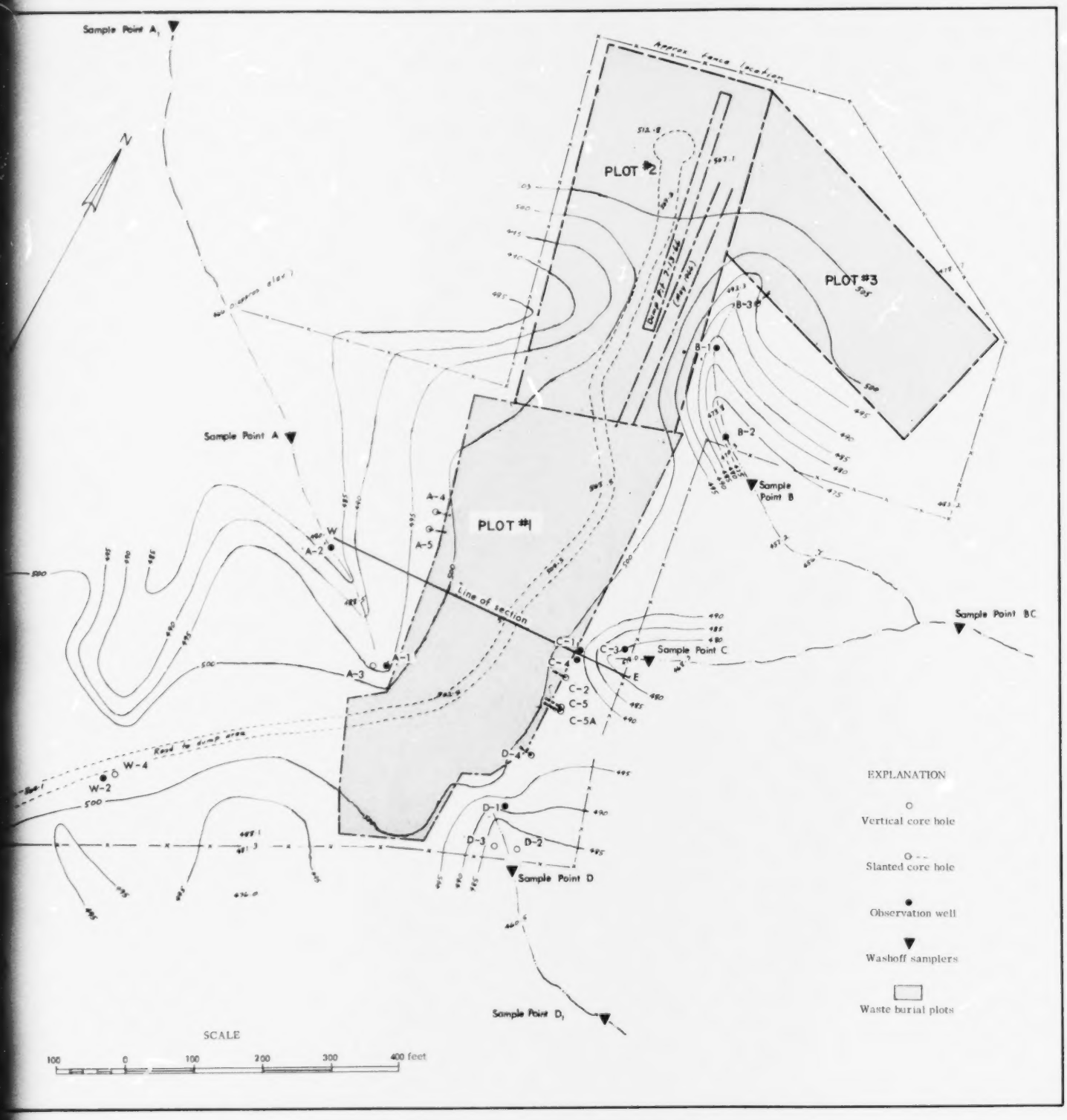

e showing the locations of the waste burial plots and the sampling sites and test wells

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EXPERIMENTAL PROCEDURE

During the course of the investigation of the pesticide dump, about 320 samples of water and earth-materials were collected from various locations in and near the dump site. The location of the sampling sites are shown on figure 3. Special precautions were taken to ensure that the sampling apparatus and sample containers were not contributors of contamination.

About 90 samples of runoff and sediment washoff were collected from the sampling devices that were installed in the 4 ravines or draws leading away from the dump. The washoff sampling apparatus consisted of a V-shaped aluminum pan and a glass sample bottle. The pan served to divert the sediment-laden washoff and convey it into the glass bottle which was placed under the open nose of the pan. The bottle was covered with a stopper through which an aluminum funnel and an air bleed protruded to trap the sample in the bottle. After each heavy rainfall the sample-filled bottle was retrieved and capped for shipment to the laboratory. In addition, a sample of the material retained on the V-shaped pan was collected for shipment to the laboratory. After each sample collection, the sampling apparatus was mechanically cleaned, rinsed with Nanograde® hexane and reassembled with a fresh sample bottle.

An additional 16 samples of runoff and sediment were collected from Pugh Creek. One of these samples was collected at a sampling site upstream from the disposal site (fig. 3, inset map). The remainder was collected during periodic visits to the downstream site (fig. 3, inset map). During most of these visits, a sample of the bedload material was also collected.

Samples of ground water were collected from the nearest available wells tapping each of the 3 water-bearing zones. Samples from the perched water zone were obtained from wells A-1, A-2, B-1, and B-2 which are located on the periphery of the dump site (fig. 3). Samples from the water-table aquifer were obtained from the King and Sterling wells (fig. 3, inset map) and samples from the artesian aquifer were obtained from the Velsicol well near the entrance to the disposal site.

To investigate the occurrence of pesticides in the subsurface, about 200 core samples were obtained at selected depths from 18 test wells that were drilled at various distances from the margins of the disposal site. The locations of these test wells are also shown on figure 3. Six of these wells were drilled on an angle to obtain samples of earth material from different stratigraphic horizons beneath the disposal pits without penetrating the burial trenches.

As the cover soil at the disposal site was known to be contaminated (table 6), it was necessary to develop core sampling techniques that would not spread the contamination in the drilling process. To avert this danger, a Porter fixed-piston drive sampler was used because the core barrel of this device remains closed until the piston is removed for sampling by means of a center rod. To obtain a core sample, the

device was inserted into the borehole and the barrel was driven 6 or 8 inches into the bottom of the hole before the piston was removed. Then, with the core barrel opened at the bottom, the sampler was driven an additional 2 to 4 feet to obtain the core sample.

Loading and unloading the core barrel were carefully attended. Prior to use, the brass core barrel liners and caps were first washed in alcoholic sodium hydroxide, then in dilute hydrochloric acid, and finally rinsed in distilled water. After air drying, the liners and caps were wrapped separately in aluminum foil and sent to the test site. In the coring process the core barrel and all attachments were thoroughly cleaned and rinsed with Nanograde® hexane. Then the liners were unwrapped and inserted into the core barrel. Next, the center rod with its fixed piston was positioned in the core barrel so that the bottom end of the core barrel was completely closed. As an additional precaution, glass wool was packed into the core barrel extension around the piston rod just above the core chamber. This was done to prevent dirt from dropping down into the core barrel during the coring operation.

After retrieving the core barrel from the borehole, the core-filled liners were removed from the barrel and wrapped in new foil for shipment to the laboratory. Polyethylene gloves were worn by field personnel during the latter step to avoid contaminating the sample.

As previously stated, this study involved a considerable number of laboratory analyses. To achieve the desired objectives, the analyses were performed by two laboratories. The water, soil, and sediment samples were analyzed by the USGS pesticide laboratory at Sacramento, California, and the core samples were analyzed by the USGS pesticide laboratory at Menlo Park, California.

Gas chromatography using both electron capture and microcoulometric modes of detection was used as the principal method of analysis for this study. The high resolving characteristics of the gas chromatograph enables the analyst to separate and identify the components in a mixture of volatile organic compounds. The electron capture detector is extremely sensitive, capable of detecting a few picograms (10^{-12} grams) of compound, but is nonspecific. The microcoulometric detector, while less sensitive, requiring at least 10^{-9} grams of compound, specifically detects halogenated components. Gas chromatography is a widely accepted method for the determination of pesticide residues.

Analysis of Water and Sediment Samples

Owing to the nature of the sampling devices used and the runoff conditions, the runoff and sediment washoff samples contained varying proportions of water and sediment--from dry soil to essentially all water.

Whenever it was possible to do so, the water and sediment were separated and analyzed separately. Samples were analyzed by microcoulometric titration or by electron capture gas chromatography or both depending upon the concentration of organic material in the sample.

Water Samples

Water samples obtained from the wells and Pugh Creek were sufficiently low in color and interfering organic matter that cleanup was not required. Analysis was accomplished by simple extraction of 1-liter samples with 75 ml (milliliters) of hexane, evaporation of the extractant to 5.0 ml, and injection of 5.0 µl (microliters) into the gas chromatograph (Lamar and others, 1966, p. 187). In all cases, injections into two different columns were made. Operating conditions for the electron-capture gas chromatographic procedure were as follows:

Instrument	:	Aerograph Hy-FI Model 600-D, with a Wilkens Model 328 isothermal temperature controller
Columns	:	1. 1/8 inch by 5 foot pyrex glass, packed with 60/80 mesh Gas-Chrom Q coated with 5 percent w/w (weight per weight) DC 200
		2. 1/8 inch by 5 foot pyrex glass, packed with 60/80 mesh Gas-Chrom Q coated 5 percent w/w QF-1
Oven temperature	:	187°C
Detector	:	Electron-capture, concentric tube design
Carrier gas	:	Nitrogen at 40 ml/min.
Injection volume	:	5.0 microliters

Water samples obtained from surface runoff down the 4 draws generally contained sufficient chlorinated organic compounds to permit microcoulometric analysis in addition to the more sensitive electron capture gas chromatography.

These samples usually contained large amounts of extraneous material and required the application of a cleanup procedure prior to analysis. Preparation for analysis included extraction of 1-liter samples with 75 ml of hexane, evaporation of the extractant to 0.5 ml, and cleanup of the concentrated extract by column chromatography. Woelm alumina deactivated before use with 5 percent w/w water (de Faubert Maunder and others, 1964), was used in a micro column as described by Goerlitz and Lamar (1967). When the 0.5 ml of the extract was eluted through a 4 by 30 mm (millimeter) alumina column with 5.0 ml of hexane, the first 1.5 ml of eluate contained any heptachlor in the sample. The second eluate fraction of 4.0 ml contained any dieldrin, endrin, or heptachlor epoxide. Following elution, the two fractions were prepared for gas chromatographic analysis by dilution with hexane to 2.0 and 5.0 ml respectively.

Since the dieldrin fraction seldom contained sufficient material to permit microcoulometry, it was analyzed by injection of 5.0 µl into two electron-capture gas chromatographic columns. The heptachlor fraction, which always contained the major amount of chlorinated organics present in any sample, was analyzed by injection of 5.0 to 40.0 µl into the microcoulometer. Operating conditions for the microcoulometric analysis were as follows:

A. Chromatograph

Column	:	1/4 inch by 5 foot pyrex glass, packed with mesh Gas Chrom Q coated with 100 percent w/w DC 200
Injection temperature	:	210°C
Column temperature	:	187°C
Carrier gas	:	Nitrogen at 120 ml/min.

B. Microcoulometer

Inlet sweep gas	:	Nitrogen at 10 ml/min.
Combustion gas	:	Oxygen at 60 - 70 ml/min.
Inlet temperature	:	220°C
Combustion tube temperature	:	920 ± 10°C

Soil and Sediment samples

Sample material collected for analysis in this category included: soil from the surface of the dump area; surface soil one mile away from the dump; sediment transported down the draws during runoff events; suspended sediment and bed material from Pugh Creek; and clay hauled in to repack the wells drilled to monitor water movement away from the dump site.

Of these materials, only the soil from the surface of the dump proper and the sediment moved down the draws by rainfall contained chlorinated organic compounds in sufficiently high concentration to allow analysis by microcoulometry. Other soil and sediment samples were analyzed by electron capture gas chromatography following suitable sample preparation.

Most samples were received in a moist condition. To avoid the risk of losing volatile components during drying, all samples were analyzed as received. The dry sample weights were computed from moisture determinations and the results reported on a dry weight basis.

In order to improve extraction and removal of organics from the moist materials, all samples were extracted with acetonitrile according to the following procedure. A 25- to 100-gram sample of soil was extracted with 25 to 100 ml (milliliters) of acetonitrile and filtered. The filtered extract was diluted with an equal volume of water and then 25 ml of hexane were added. After separation and drying, the hexane was reduced in volume to 0.5 ml. These extracts were subjected to the alumina cleanup procedure previously described and analyzed by either microcoulometry or electron capture gas chromatography, depending on the concentration of organic material present. This method proved to be an efficient method for the extraction of the four pesticides from the soil sample.

Discussion of results

It should be noted that the four pesticide compounds (dieldrin, endrin, heptachlor, and heptachlor epoxide) could not always be identified among the chlorinated hydrocarbon materials that were observed. Nevertheless, the observed compounds are believed to be closely related and of equal significance in indicating the contamination of the environment of the dump site. Therefore, the fact that the analytical results are, in some instances, presumptive rather than conclusive does not detract from their use in describing the extent and degree of contamination from the disposal pits.

Wells - The analytical results of water samples from wells are given in table 1. Analysis of samples obtained from the 3 water-supply wells (King, Sterling, and Velsicol wells) nearest the dump site showed no evidence of contamination by chlorinated hydrocarbons. However, the water samples that were obtained from 3 out of 4 of the shallow wells (A-2, B-1, and B-2), located on the margin of the dump site did contain chlorinated hydrocarbons. These wells were sampled, pumped dry, allowed to rewater, and resampled. The values reported in table 1 for each sample are those obtained by electron capture gas chromatography utilizing two different columns. The quantities of the 4 pesticide compounds found, however, are relatively small, ranging from 0.01 to 0.11 µg/kg (micrograms per kilogram).

Pugh Creek - Results of analysis of water and sediment samples obtained from Pugh Creek are given in table 2. These data indicate the presence of small amounts of chlorinated hydrocarbons in the stream bottom sediment 1 1/2 miles downstream from the disposal site. The quantity found is in excess of that prevalent in the area away from the dump site and is therefore presumed to have originated from the pit area.

Only 2 samples of water gave any indication of the presence of any of the 4 primary chlorinated compounds. Hence, contamination of the water in Pugh Creek from the disposal pits is only an assumption.

Draws - The analytical results of runoff and washoff samples from the 4 draws draining the disposal site are given in table 3. Results of two-column electron capture gas chromatography indicated the presence of dieldrin, endrin, and heptachlor epoxide in most of the draw samples tested. The presence of heptachlor was indicated by microcoulometric titration following one column separation but duplication of these results on a second column could not be obtained. It must be concluded, therefore, that heptachlor was not present in any of the draw samples analyzed, but a chlorinated compound similar to heptachlor was detected. The amounts of these compounds that were found ranged from as little as 0.02 µg/kg to as much as 1,600 µg/kg.

It was generally noted that higher concentrations were found in those samples that were collected from the bottle portion of the samplers than were found in the all-sediment samples that were retrieved from the pan portion of the samplers. This was probably due to loss of the more volatile organic materials from the pan sample as a result of exposure to the atmosphere and sunlight before the samples were picked up by field personnel.

Although a great deal of variation can be noted in the concentrations of organic materials found, both as to time and place, there does appear to be a definite decrease in concentration in each draw with increase in distance away from the pit area. This observation, together with the occurrence of high concentrations in samples with sediment, indicates the principal mode of transport to be adsorption on sediment particles. More precise quantitative relationships could not be developed owing to the limited data available and lack of adequate sampling control.

Analysis of Core samples

The core samples were analyzed for dieldrin, endrin, heptachlor, and heptachlor epoxide. In addition, the total organic chlorine content, moisture content (Association of Official Agricultural Chemists, 1940, p. 1) and pH (Peach, 1965, p. 914) of most of the samples were determined. As a control, the top and bottom sections of each core sample were analyzed separately to identify any contamination that might have been introduced during the coring process. The routine analysis of the cores consisted of the following procedures.

Extraction

A 50.0 g sample of pulverized soil was shaken in an acetone-hexane solvent. The extract was decanted from the soil into a separatory funnel. This was repeated three times and the combined extracts were washed with water to remove the acetone. The extract was dried over sodium sulfate. The dried extract was then either concentrated or diluted to a known volume. This method was found to be adequate for the extraction of the four pesticides from the soil samples.

Gas Chromatography

The gas chromatographic analysis was performed in a stepwise manner. First, the extract was analyzed by electron capture gas chromatography using a 1/8 inch by 5-foot Gas Chrom Q column coated with 5.0 percent w/w DC-200 and 0.5 percent w/w Carbowax 20M. Further concentration adjustments and cleanup (as described under Analysis of Water and Sediment Samples) if indicated, were performed at this time. The extract was analyzed a second time by electron capture gas chromatography using a 1/8 inch by 5-foot Gas Chrom Q column coated with 5.0 percent w/w QF-1 and 0.5 percent w/w Carbowax 20M. If a particular compound of interest was indicated by the previous two analyses, a third analysis was made on a 1/8 inch by 5 foot Gas Chrom Q column coated with 2.3 percent w/w Versamid 930. If the concentration of the component(s) was high enough, microcoulometric detection was employed for the third analysis, otherwise the more sensitive electron capture detector was used again. If the soil extract had only 3 or 4 major components, gas chromatographic identification was made using 3 different types of columns. Further, when a component was present in amounts large enough to permit microcoulometry, agreeing quantitative data from the two detection systems was considered essential to identification. Gas chromatography alone was not sufficient for analysis of more complex mixtures, therefore, thin-layer chromatography was used for preliminary separation of components.

Thin-Layer Chromatography

Microliter quantities of the extract were spotted on a silica gel thin-layer chromatographic plate and developed with hexane. The components that migrated a distance equal to that of standards spotted and visualized on the same plate were scraped from the plate and extracted into hexane. The resulting solution was then subjected to three-column gas chromatographic analysis.

Total Chlorine

To provide a more complete assay of the soil contaminants than could be obtained from the measurement of only a few of the identifiable components by conventional gas chromatography, a method was devised whereby the total chlorine content of the volatile extractables could be measured. The total chlorine analysis involved temperature programmed microcoulometric gas chromatography on a very short column. The soil extract was concentrated to a suitable volume and injected onto a 3 percent w/w Apiezon L column, 1/4 inch O.D. by 3.0 inches long. The solvent was swept from the column with nitrogen gas at room temperature. After a predetermined time the column was heated to 300°C in two minutes. Following combustion of the eluate the total chlorine was measured with a microcoulometric titrating cell. An experimental check of the total chlorine procedure demonstrated that this technique is applicable to determining the total chlorine content of compounds having boiling points as low as hexachlorocyclopentadiene and as high as methoxychlor. The total chlorine in an extract from 50 g of soil sample was measured to a lower limit of 0.5 µg/kg.

Discussion of Results

When waste materials were detected in significant amounts in the core samples they appeared as a complex mixture. However, none of the compounds of primary interest (dieldrin, endrin, heptachlor and heptachlor epoxide) was positively identified (limit of measurement 0.1 micrograms per kilogram) in the 200 core samples that were examined. Initial qualitative results suggested the presence of heptachlor, but comparison of electron capture and microcoulometric data showed a marked difference in response. This observation indicated that either another compound, or compounds, eluted with heptachlor, on both DC-200 and QF-1 columns, or that heptachlor was not present. The introduction of a third analytical column, Versamid 930, provided the necessary resolution of components and proved that the compound in question was not heptachlor.

Because none of the components extracted from the soil samples was identified as one of the four compounds of primary interest, the analysis was expanded to include other pesticides and chemicals involved in the manufacture of pesticides. In addition to the previously mentioned pesticides the compounds aldrin, chlordene, chlordenechlorohydrin, hexachlorobicycloheptadiene, hexachlorocyclopentadiene and isodrin were included. Owing to the multiplicity of components in the soil extract it was not possible to identify the individual compounds by simple gas chromatographic analysis.

Adequate preliminary separations by column adsorption chromatography were not attained but separations were obtained on thin-layer chromatographic plates. A component of the mixture that migrated similar to an isodrin standard was removed from the plate. The hexane extract of the thin-layer adsorbent showed by three column gas chromatography that isodrin was one of the components present in the waste material found in the core samples. Since a number of other compounds migrated with isodrin on the thin-layer plate, infrared spectroscopy could not be used to further confirm the identity of this compound.

Considerable effort was expended in attempting to identify the compounds found in the core samples so that quantitative data could be obtained. Quantitative data were required to describe the extent of waste movement from the disposal trenches. Isodrin was the only component of the complex mixture that was identified. This fact alone was inadequate for measurement of waste in the contaminated soil. It was observed, however, that virtually all of the gas chromatographable components of the waste material in the soil extracts were chlorinated compounds. In light of this, a method for the analysis of the soil extracts for total chlorine was devised. The successful application of this technique, while not qualitative with respect to individual compounds, was found to give an overall quantitative estimation of waste materials in the core samples.

Tables 4 and 5 show the results of the total chlorine analyses, expressed in terms of dry soil samples. The concentrations reported for well W-4 (excluding the surface core sample) are believed to be representative of the natural or background concentrations of total organic chlorine in the dump area. For this reason, a concentration of about

double the highest background value or 5 µg/kg (micrograms per kilogram) was chosen as representative of the threshold of contamination. Using this value, the contaminated core samples can be readily identified from the values given in tables 4 and 5.

The relationships between the depth of contaminated core samples and subsurface features of the dump site are shown diagrammatically in figure 4, an east-west cross-sectional view of burial plot number 1. In order to retain the relative positions of the core samples with respect to the margins of the burial plot, the test wells were projected into the cross-section parallel to the margins of the burial plot.

Core samples taken from directly beneath the burial trenches were the most contaminated. A relatively high degree of contamination was found to extend from the bottom of the pits down to the first bed of clayey material--some 20 to 25 feet below the bottom of the pits. Within this clayey bed the concentration of chlorine from pesticide wastes decreased sharply to less than 5000 µg/kg, and core samples taken from a few feet below the first clayey bed down to the top of the zone of saturation contained 11 µg/kg or less of chlorine from pesticide waste.

Cores from wells drilled vertically beside the waste pits showed considerably less contamination in all zones. Samples taken from sand number 1 within a lateral distance of 5 to 10 feet of the trenches contained only about 175 µg/kg or less of chlorine from pesticide waste. Samples from the same sand at greater distances away contained little or no contamination from the waste material buried in the disposal trenches.

It is evident from the information shown on figure 4 that the predominant direction of movement of the wastes from the disposal pits is downward. It is also evident that some lateral movement of the wastes has taken place, particularly along the beds of clayey earth material. This leads to the interpretation that the downward movement of the wastes is rapid until a clayey stratum is reached. The clayey stratum, in turn, serves to retard or attenuate but does not arrest the downward movement of the wastes. Thus, the downward movement of the wastes can be expected to continue beyond the limits shown in figure 4. Conceivably, the wastes will move downward until an effective barrier is reached.

POTENTIAL CONTAMINATION OF GROUND-WATER SUPPLIES

Having established the existence of a subsurface zone of contamination from the disposal pits, it is imperative that the potential contamination hazard to local and contiguous ground waters be thoroughly evaluated. In view of the severity of the risks involved, it must be assumed that any ground water originating in or passing through the contaminated zone is susceptible to contamination and therefore becomes a serious threat to any water supplies downgradient from the disposal area. Thus, far, evidence has been presented to indicate that ground water in both the perched water zone and the water-table aquifer is susceptible to contamination from the disposal pits. There is, however,

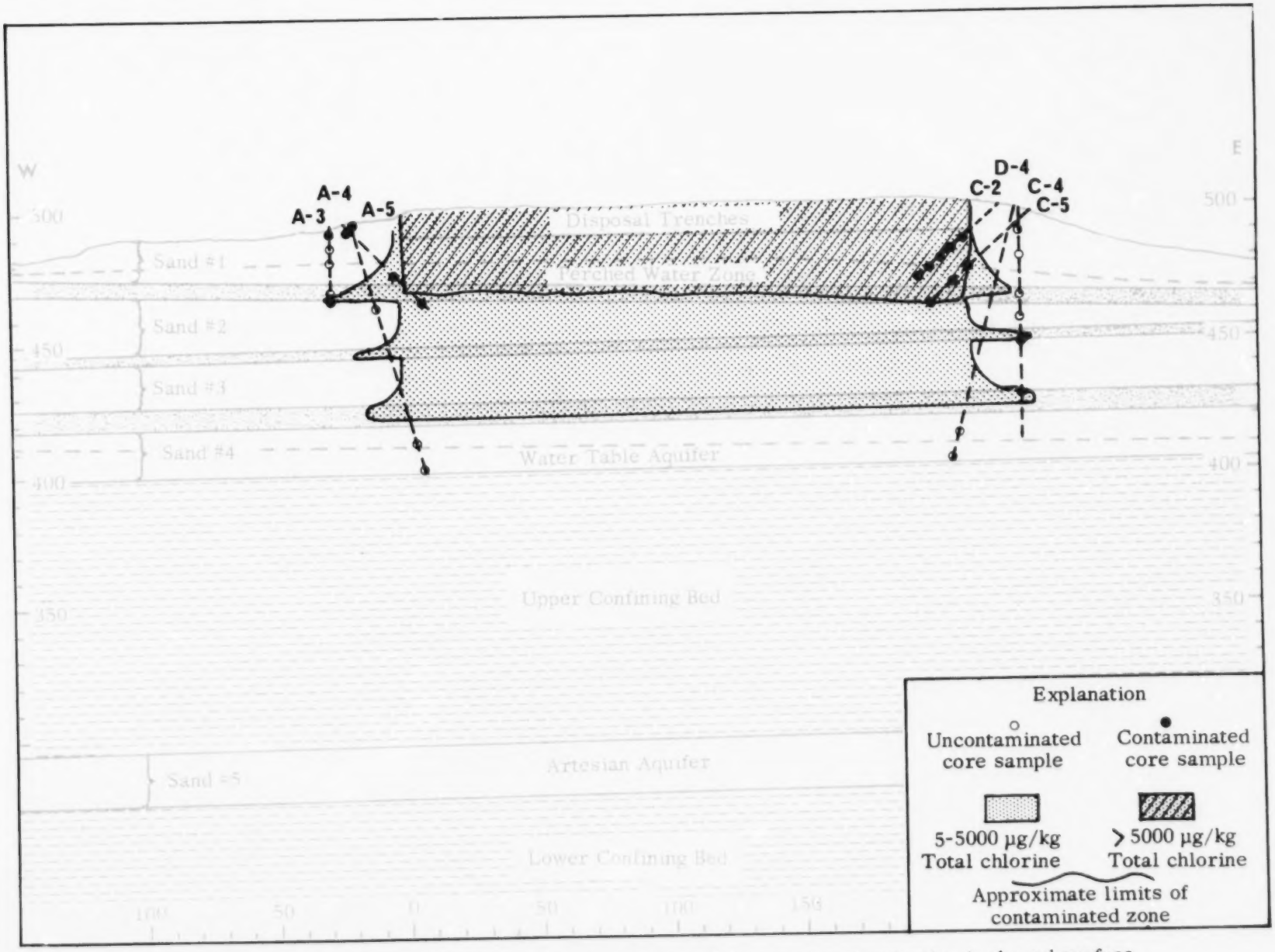

Figure 4--Cross-section of dump site showing extent and degree of contamination in the subsurface

little likelihood that ground water in the artesian aquifer will ever be exposed to contaminants from the disposal pits owing chiefly to the interposition of the clayey upper confining bed which constitutes a formidable barrier to the movement of both ground water and contaminants. Hence, the most immediate and, for all practical purposes, the sole threat to ground-water supplies is the entrainment of contaminants in the flow systems of the perched water zone and the water-table aquifer.

Potential Movement of Contaminants in the Perched Water Zone

The movement of ground water in the perched water zone is determined by the configuration of the free-water or upper surface of that zone. In general, the free-water surface is characterized by mounds and depression which coincide approximately with topographic hills and valleys. Hence, water that enters the perched zone from the land surface is prone to move in the general direction of slope of the perched water surface which usually coincides with the slope of the land surface. It reappears at the land surface in the valleys along the line of intersection of the land surface and the base of the permeable formation in which the water is perched. Thus, within the disposal area, water in the perched zone tends to move radially outward from beneath topographic highs toward the nearest margins of the perched zone.

Observations of water levels in the perched zone (table 9) marginal to the disposal area indicate the presence of a mound beneath the disposal pits. Hence, water in the perched zone within the zone of contamination has the potential to move outward from the disposal area toward the surrounding draws. Figure 5 shows the areal extent of the perched zone that is susceptible to contamination from the existing disposal pits. The northwestern, eastern, and southeastern limits of the area susceptible to contamination (solid lines) coincide with the limits of the perched zone. The northern and southwestern limits are no flow boundaries as a result of opposing gradients.

It is conceivable that withdrawals from the perched water wells located a few tens of feet outside of the no-flow boundaries could temporarily displace the no-flow boundary and thereby induce water from the potentially contaminated zone to enter the well. Surely any wells tapping the perched water zone within the potentially contaminated area would be susceptible to contamination.

It should be noted that the rate of movement of subsurface water is exceedingly slow and a considerable period of time might elapse before the potentially contaminated zone is contaminated. For example, measurements of the hydrologic properties of the sand containing the perched water zone (table 10) indicate that under the prevailing hydraulic gradient (2 percent) the maximum velocity of water movement in the perched zone is about 1 foot per day. At this rate, water in the perched zone beneath the disposal pits could reappear at the land surface within 100 days but it could take at least 1000 days for it to reach the most remote limits of the perched zone that is down gradient from the pits.

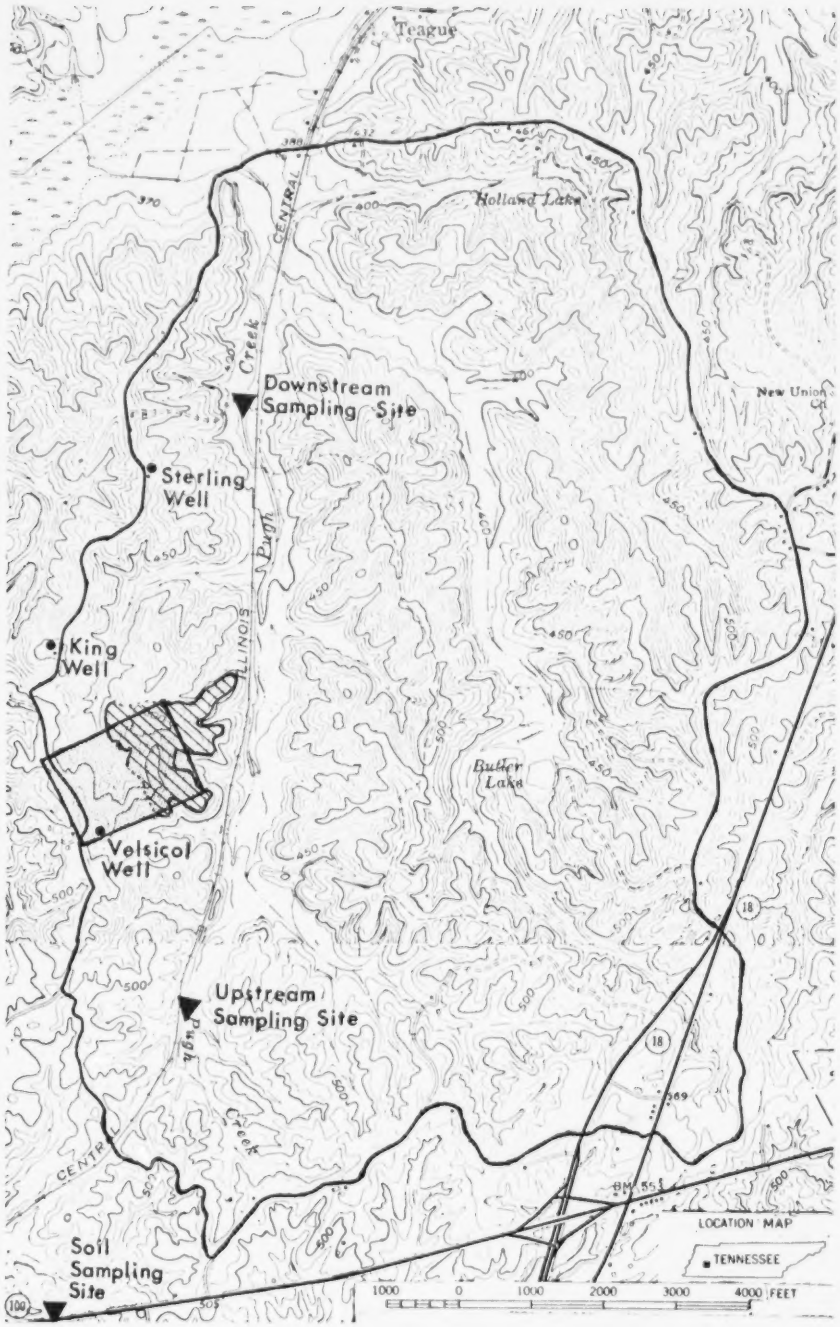

Figure 5--Map of the Pugh Creek basin showing the areal extent of the perched water zone that is susceptible to contamination from the disposal pits (cross-hatching).

Potential Movement of Contaminants in the Water-Table Aquifer

The direction of movement of ground water in the water-table aquifer is significantly different from that in the perched water zone owing to the differences in the configuration of the free water surfaces of the two water bodies. In comparison, the free water surface (water table) of the water-table aquifer has a very gentle gradient from the topographic divide of Pugh Creek valley toward outcrops of the water-table aquifer in the channels of Pugh Creek and its perennial tributaries. Hence, in the vicinity of the disposal area, ground water in the water-table aquifer moves toward the north and east.

The direction of water movement in the water-table aquifer in the vicinity of the disposal site is shown in figure 6, a generalized flow net drawn on the basis of water-level observations in early April 1967. The portion of the water-table aquifer that is susceptible to contamination from the disposal pits is also shown on figure 6. Included are the portions of the aquifer that are either directly beneath or downgradient from (1) the disposal pits, (2) the portion of the perched water zone that is subject to contamination, and (3) the draws which carry contaminated washoff from the disposal area.

Thus, water entering or passing through the water-table aquifer from potentially contaminated sources will tend to move northeasterly toward Pugh Creek. Moreover, the contaminants entrained in this flow system could eventually be discharged into Pugh Creek. According to Moore (1965, p. 20) the average coefficient of permeability of the sand comprising the water-table aquifer is 570 gpd/ft^2 (gallons per day per square foot). If it is assumed that the maximum coefficient of permeability of the water-table aquifer at the dump site is 1000 gpd/ft^2, the minimum time that would be required for water to move from beneath the disposal pits to Pugh Creek (a distance of about 1500 feet) under the prevailing water-table gradient is about 5 years.

The foregoing description of the contamination potential of the water-table aquifer will prevail unless or until the prevailing water-table gradient is altered by heavy pumping from the aquifer in the vicinity of the disposal area. In that event, the prevailing flow system in the water-table aquifer could be modified and thereby allow water from the portion of the aquifer that is suceptible to contamination to move toward the point or points of withdrawal. It should be noted, however, that this hazard would exist only while pumps were actually in operation because as soon as the pumps were turned off water levels would tend to recover and the prepumping flow pattern would doubtless be reestablished within a matter of hours.

The susceptibility of wells tapping the water-table aquifer to contamination from the disposal pits is dependent upon (1) the magnitude and duration of pumping, (2) the distance between the well site and the nearest possible source of contaminated ground water, and (3) the relative position of the well with respect to the prevailing west-to-east water-table gradient. None of the wells tapping the water-table aquifer

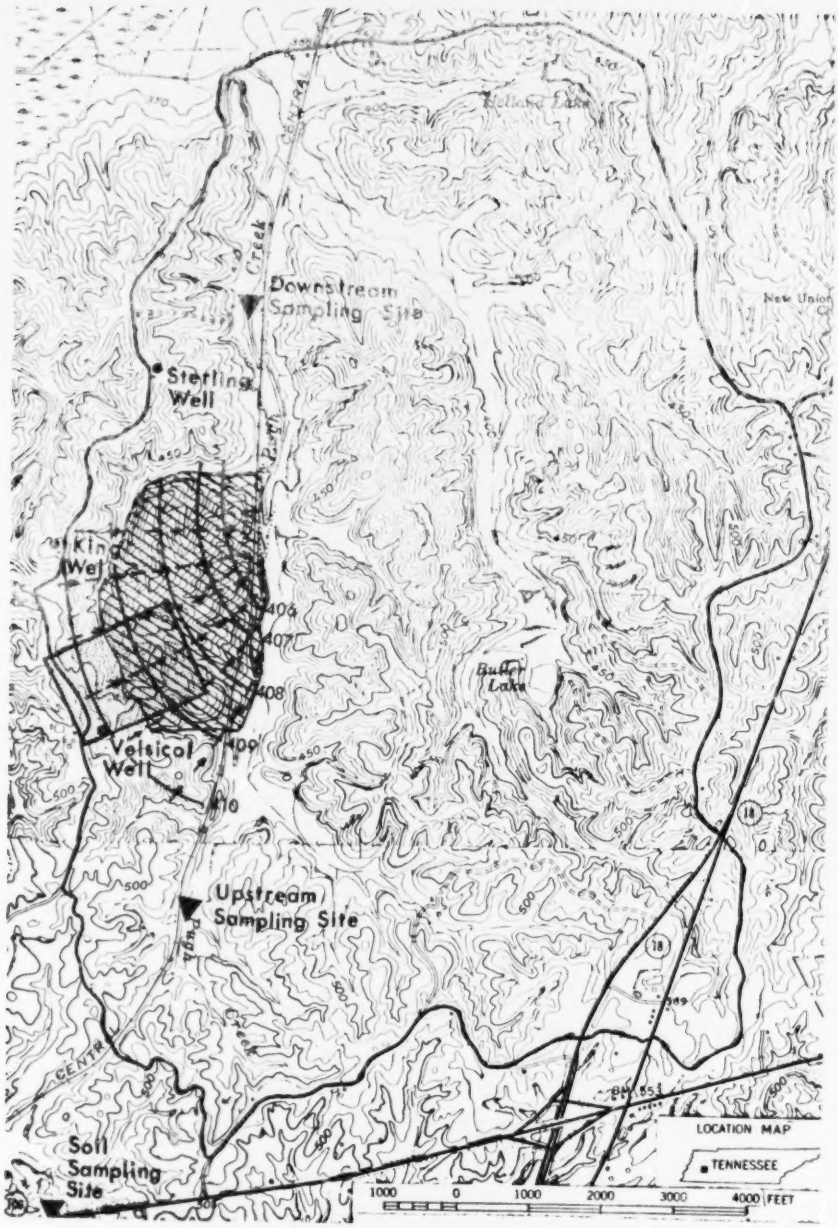

Figure 6--Map of the Pugh Creek basin showing the direction of groundwater movement in the vicinity of the pesticide waste disposal site (dashed arrows), and the areal extent of the water-table aquifer that is susceptible to contamination from the pesticide waste disposal pits (cross-hatching).

in the neighborhood of the disposal site are capable of pumping in excess of 10 gpm (gallons per minute) and none are pumped for more than a few hours at a time. Hence, the particles of water that are withdrawn from the well are obtained from storage in the aquifer not more than a few feet from the well, whereas the nearest well is at least 800 feet from a potential source of contamination. Furthermore, all of these neighborhood wells are located with respect to the disposal site either upgradient or perpendicular to the gradient. There is, therefore, no possibility for any existing water-table wells to produce potentially contaminated water from the water-table aquifer.

To determine just how susceptible a given well location might be to contamination from the disposal site, computations were made of the maximum distance water would travel through an ideal aquifer having the hydraulic properties assigned to the water-table aquifer for any specified period of pumping. The values used in the computations were selected to insure maximum velocities of ground-water movement. A rate of pumping of 40 gpm was used because it is the maximum rate of pumping that the water-table aquifer can possibly sustain within a radius of several miles from the disposal site. Similarly, a value of 1000 gpd/ft^2 was used for the coefficient of permeability because it is the highest value that can be inferred from the character of the aquifer. A storage coefficient of 0.2 was used not only to reflect water-table conditions, but also to insure a maximum radius of influence of pumping.

The results of the computations are presented graphically in figure 7. The dotted line shows the influence of pumping alone on the time-of-travel of ground water and should be used only where the water table is perfectly flat. The dashed line represents the resultant of the influence of pumping acting perpendicular to the force of the prevailing (0.13 percent) water-table gradient. The solid line represents the resultant of the influence of pumping acting in opposition to the prevailing gradient. Both the solid line and the dashed line terminate at the distance from the well where the influence of pumping is insufficient to overcome the force of the prevailing gradient.

To illustrate the use of the graph, assume that the King well is turned on and pumped continuously at 40 gpm. This well is 800 feet upgradient from the draw that carries contaminated surface washoff from the disposal pits. Hence, water that recharges the water-table aquifer from the centerline of the draw has been exposed to contaminants from the dump area. To determine how long the King well would have to be pumped at 40 gpm to allow potentially contaminated water to reach the well, enter the graph (fig. 7) on the vertical scale at 800 feet, follow across to its intersection with the solid line and read the time value on the horizontal scale. The answer is 6200 days or 18 1/2 years. If the pump were turned off at any time within the 18 1/2 years, the natural gradient between the well and the draw would be restored and the potentially contaminated water would move in the opposite direction away from the well.

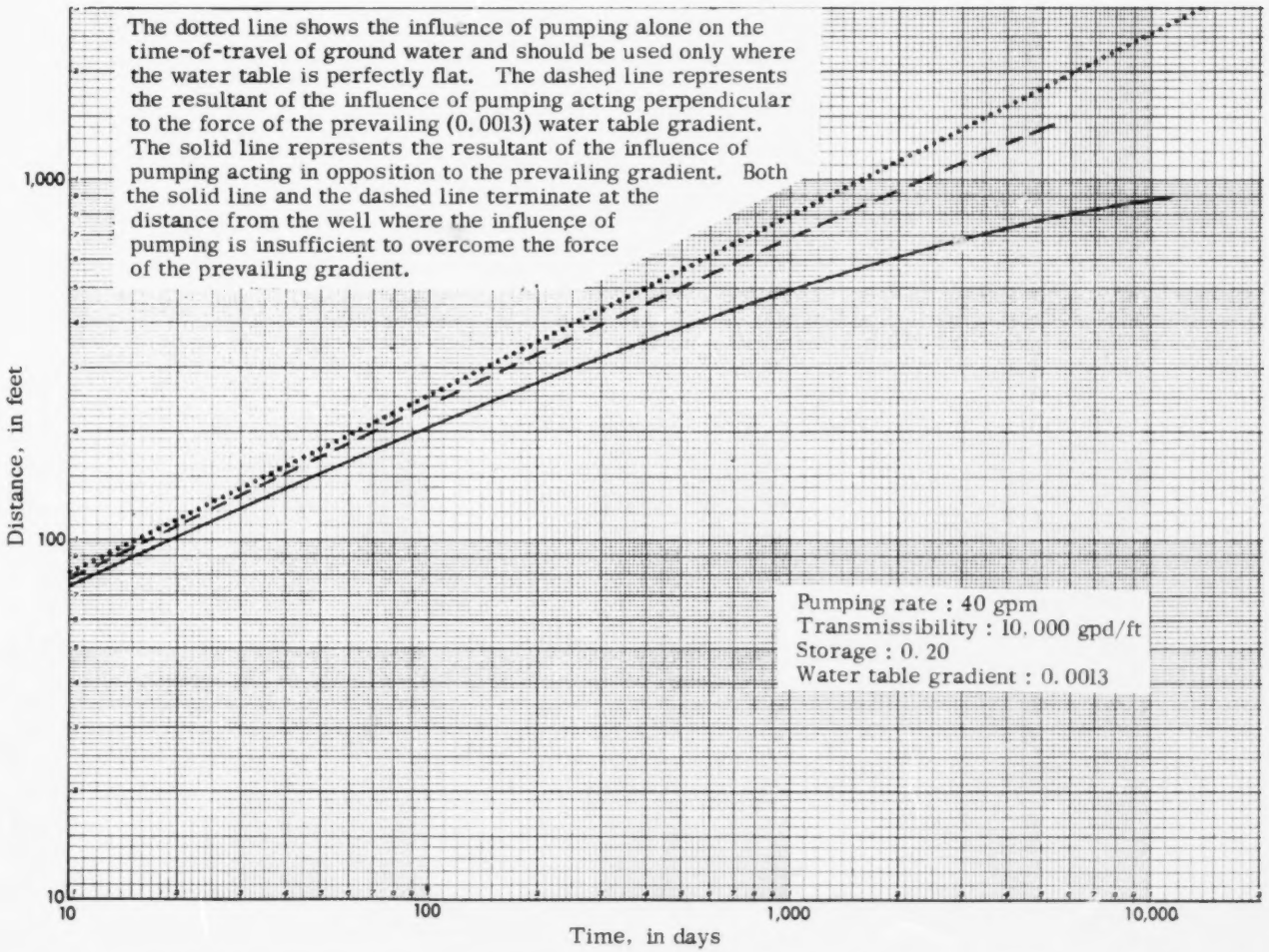
The dotted line shows the influence of pumping alone on the time-of-travel of ground water and should be used only where the water table is perfectly flat. The dashed line represents the resultant of the influence of pumping acting perpendicular to the force of the prevailing (0.0013) water table gradient. The solid line represents the resultant of the influence of pumping acting in opposition to the prevailing gradient. Both the solid line and the dashed line terminate at the distance from the well where the influence of pumping is insufficient to overcome the force of the prevailing gradient.
Pumping rate : 40 gpm
Transmissibility : 10,000 gpd/ft
Storage : 0.20
Water table gradient : 0.0013
Distance, in feet
1,000
100
10
10
100
1,000
10,000
Time, in days

Figure 7--Graph showing the theoretical time-of-travel of ground water in response to continuous pumping from an ideal aquifer having the hydraulic characteristics determined for the water-table aquifer in the vicinity of the pesticide waste disposal site.

The dashed line should be used to determine the length of time the Sterling well would have to be pumped continuously at 40 gpm to induce potentially contaminated recharge water from the draw to reach that well. The answer is 5600 days or about 15 years if indeed this well could overcome the force of the prevailing water-table gradient and divert water to the north from such a long distance to the south. Moreover, in the event this well were turned off at any time during the 15 years, the contaminants would cease moving northward and begin moving toward the east.

Wells at greater distances than those mentioned would, of course, require greater magnitudes and longer periods of pumping to permit potentially contaminated water to reach them. The water-table aquifer is incapable of sustaining such yields, and hence the potential contamination hazard for such wells is nil.

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Table 1.--Analytical results of ground-water samples from wells

Sample source	Date sampled	Quantities of organic compounds that elute at the same retention time as the following pesticides (µg/kg) 1/				Remarks
		Dieldrin	Endrin	Heptachlor	Heptachlor epoxide	
			Artesian aquifer			
Velsicol well	10-14-66	0.00	0.00	0.00	0.00	
Do.	10-14-66	0.00	0.00	0.00	0.00	
			Water table aquifer			
Sterling well	10-14-66	0.00	0.00	0.00	0.00	
J. H. King well	10-14-66	0.00	0.00	0.00	0.00	
			Perched water zone			
Well A-1	2-16-67	0.00	0.00	0.00	0.00	before pumping
Do.	2-16-67	0.00	0.00	0.00	0.00	after pumping
Well A-2	2-16-67	0.02	0.01	0.02	0.01	before pumping
Do.	2-16-67	0.01	0.01	0.02	0.00	after pumping
Well B-1	2-16-67	0.07	0.10	0.11	0.00	before pumping
Well B-2	2-16-67	0.07	0.04	0.06	0.01	before pumping
Do.	2-16-67	0.06	0.05	0.07	0.02	after pumping

1/ Limit of measurement is 0.01 µg/kg

Table 2.--Analytical results of surface water and sediment samples from Pugh Creek

Sample source	Date sampled	Quantities of organic compounds that elute at the same retention time as the following pesticides (µg/kg) 1/				Remarks
		Dieldrin	Endrin	Heptachlor	Heptachlor epoxide	
			Upstream sampling site			
Streamflow	5-23-66	0.00	0.00	0.00	0.00	
			Downstream sampling site			
Streamflow	5-23-66	0.00	0.00	0.00	0.00	
Do.	5-23-66	0.20	0.00	0.03	0.00	1% sediment
Do.	7-12-66	0.00	0.00	0.00	0.00	1% sediment
Do.	10-14-66	0.00	0.00	0.00	0.00	
Bedload	10-14-66	0.00	0.00	0.00	0.00	Water portion
Bedload	10-14-66	0.24	0.10	3.2	0.0	Sediment portion
Streamflow	10-19-66	0.00	0.00	0.00	0.00	
Do.	12-02-66	0.00	0.00	0.00	0.00	30% sediment
Do.	12-30-66	0.00	0.00	0.00	0.00	
Bedload	12-30-66	0.00	0.00	0.00	0.00	Water portion
Bedload	12-30-66	0.22	0.1	0.12	0.0	Sediment portion
Streamflow	4-28-67	0.01	0.00	0.00	0.00	Water sample
Bedload	4-28-67	0.00	0.00	0.00	0.00	Water portion
Do.	4-28-67	0.12	0.23	0.12	0.0	Sediment portion

1/ Limit of measurement is 0.01 µg/kg for water and 0.10 µg/kg for sediment.

Table 3.--Analytical results of runoff and washoff samples from draws.

Sample source	Date sampled	Quantities of organic compounds that elute at the same retention time as the following pesticides (µg/kg) 1/				Remarks 2/
		Dieldrin	Endrin	Heptachlor	Heptachlor epoxide	
Sampler A	5-23-66	68	23	980	1.2	B, 70% sediment
Do.	5-24-66	6.1	0.00	27	0.00	B, 8% sediment
Do.	7-12-66	0.49	0.12	34	0.07	B, 26% sediment
Do.	7-12-66	110	7.4	460	0.32	P
Do.	8-02-66	250	17	1600	0.62	B, 30% sediment
Sampler A	8-02-66	49	18	680	2.7	P
Do.	10-12-66	5.3	3.6	98.0	0.37	B, 1% sediment
Do.	10-12-66	33	6.2	100	0.70	P
Do.	12-29-66	1.6	0.86	6.8	0.09	P
Do.	12-29-66	34	28	330	2.2	B
Sampler A_1	8-02-66	1.2	0.29	7.4	0.37	B, 2% sediment
Do.	8-02-66	100	71	880	6.5	B
Do.	8-02-66	67	73	560	4.2	P
Do.	10-12-66	0.56	0.15	1.3	0.31	B, 1% sediment
Sampler B	5-23-66	2.1	3.0	310	2.5	P
Sampler B	5-24-66	0.14	0.13	0.81	0.12	B, 1% sediment
Do.	7-12-66	0.28	0.17	47	0.28	B, 1% sediment
Do.	7-12-66	0.24	2.9	120	0.21	P
Do.	8-02-66	2.6	1.1	1000	0.73	B, 20% sediment

1/ Limit of measurement is 0.01 µg/kg for water and 0.1 µg/kg for sediment
2/ B denotes bottle sample. P denotes pan sample.

Table 3 contd.--Analytical results of runoff and washoff samples from draws.

Sample source	Date sampled	Quantities of organic compounds that elute at the same retention time as the following pesticides (µg/kg) 1/				Remarks 2/
		Dieldrin	Endrin	Heptachlor	Heptachlor epoxide	
Sampler B	8-02-66	6.4	2.7	670	1.7	B
Do.	8-02-66	1.8	1.3	210	0.24	P
Do.	10-12-66	2.1	1.7	140	0.18	B, 10% sediment
Do.	10-12-66	6.4	4.7	1300	1.9	P
Do.	12-29-66	5.1	9.5	560	2.2	P
Sampler B	12-29-66	8.0	26	970	6.8	B
Sampler BC	8-02-66	0.36	0.32	120	0.30	B, 1% sediment
Do.	8-02-66	1.0	0.92	100	0.31	B, 25% sediment
Do.	8-02-66	1.5	1.9	120	0.31	P
Do.	8-02-66	0.64	0.60	500	0.12	P
Sampler BC	10-12-66	1.5	1.2	130	0.30	B, 20% sediment
Do.	10-12-66	9.7	11	320	1.5	P
Do.	12-29-66	0.82	1.9	85	0.42	B, 50% sediment
Do.	12-29-66	8.9	7.9	450	1.9	P
Sampler C	5-24-66	0.36	0.38	50	0.07	B, 8% sediment
Sampler C	7-12-66	0.12	0.15	7.2	0.08	B, 8% sediment
Do.	8-02-66	0.52	0.30	110	0.43	B, 20% sediment
Do.	8-02-66	2.2	6.3	560	0.40	B, 15% sediment
Do.	8-02-66	1.3	1.7	600	0.22	P
Do.	8-02-66	2.2	2.2	610	0.33	P

1/ Limit of measurement is 0.01 µg/kg for water and 0.1 µg/kg for sediment
2/ B denotes bottle sample. P denotes pan sample.

Table 3 contd.--Analytical results of runoff and washoff samples from draws.

Sample source	Date sampled	Quantities of organic compounds that elute at the same retention time as the following pesticides (µg/kg) 1/				Remarks 2/
		Dieldrin	Endrin	Heptachlor	Heptachlor epoxide	
Sampler C	10-12-66	0.14	0.14	2.7	0.04	B, Water portion
Do.	10-12-66	14	10	630	2.1	B, Sediment portion
Do.	10-12-66	3.0	2.0	590	0.68	P
Do.	12-30-66	4.6	4.9	190	1.1	P
Do.	12-30-66	5.3	17	970	4.0	B
Sampler D	7-12-66	0.07	0.05	13	0.03	B, 20% sediment
Do.	8-02-66	0.24	0.25	41	0.07	B, 5% sediment
Do.	8-02-66	18	4.0	400	1.2	B, 40% sediment
Do.	8-02-66	0.96	0.04	100	0.34	B
Do.	8-02-66	0.23	0.14	57	0.05	P
Sampler D	8-02-66	0.12	0.14	53	0.02	P
Do.	10-12-66	0.08	0.12	14	0.03	B, 1% sediment
Do.	10-12-66	0.93	1.2	84	0.29	P
Do.	12-29-66	0.58	0.22	25	0.09	P
Do.	12-29-66	1.3	1.6	80	0.32	B
Sampler D_1	8-02-66	0.14	0.06	7.7	0.07	B, 5% sediment
Do.	8-02-66	0.31	0.42	7.4	0.09	P
Do.	10-12-66	0.10	0.12	1.5	0.03	B, 2% sediment
Do.	10-12-66	0.30	0.36	17	0.06	P
Do.	12-29-66	0.07	0.19	1.8	0.02	B, 1% sediment
Do.	12-29-66	0.18	0.14	2.6	0.09	P

1/ Limit of measurement is 0.01 µg/kg for water and 0.1 µg/kg for sediment
2/ B denotes bottle sample. P denotes pan sample.

Table 4. Total organic chlorine in core samples from test wells A-3, A-4, A-5, B-3, and W-4. Dashed lines in depth columns represent gaps between successive cores.

Core A-3		Core A-4		Core A-5		Core B-3		Core W-4	
Depth (feet)	Chlorine (µg/kg)	Depth (feet) [1]	Chlorine (µg/kg)	Depth (feet) [1]	Chlorine (µg/kg)	Depth (feet) [1]	Chlorine (µg/kg)	Depth (feet)	Chlorine (µg/kg)
3.0-3.5	5.6	0.0-0.5	176	0.0-0.5	18.8	0.0-0.5	208	Surface	3.3
4.5-5.0	1.7	25.5-26.0	124	33.0-33.5	1.4	94.5-95.0	10.1	3.0-3.5	.5
8.0-8.5	1.5	28.0-28.5	14.3	34.0-34.5	2.0	95.0-95.5	.7	7.5-8.0	2.7
9.5-10.0	1.5	41.0-41.5	8.4	87.0-87.5	1.1	95.5-96.0	[2] .0	10.0-10.5	1.6
13.5-14.0	2.5	44.0-44.5	[2] .0	89.0-89.5	3.3			28.5-29.0	[2] .0
14.5-15.0	1.3			98.0-98.5	[2] .0			29.5-30.0	2.4
18.5-19.0	1.1			99.5-100.0	[2] .0			58.0-58.5	[2] .0
19.0-19.5	1.5							58.5-59.0	.9
23.0-23.5	2.3							59.0-59.5	1.0
24.5-25.5	.7								
29.5-30.0	5.8								
30.0-30.5	1.7								

[1] Depth as measured along angle of slant.

[2] Less than 0.5 micrograms per kilogram, if present.

Table 5. Total organic chlorine and pH of core samples from test wells C-2, C-4, C-5, C-5A, and D-4. Dashed lines in depth columns represent gaps between successive cores

Core C-2			Core C-4			Core C-5			Core D-4		
Depth[1] (feet)	pH	Chlorine (µg/kg)	Depth (feet)	pH	Chlorine (µg/kg)	Depth[1] (feet)	pH	Chlorine (µg/kg)	Depth[1] (feet)	pH	Chlorine (µg/kg)
15.0-17.0	4.75	20,000	5.5-6.5	6.15	2.5	0.0-0.5	6.10	2.1	0.0-0.5	5.15	[2]0.0
18.0-19.0	4.35	610,000	7.5-8.0	5.75	1.5	31.0-31.5	5.80	.9	34.5-35.0	5.00	4.5
24.0-26.0	3.90	2,500,000	15.5-16.0	7.60	2.4	33.5-34.0	5.50	1.0	36.5-37.0	7.60	.9
29.0-31.0	3.45	5,700,000	17.0-17.5	6.65	3.0	38.5-39.0		23,800	85.5-86.0	7.95	1.0
34.0-36.0	3.45	6,000,000	27.5-28.0		3.2	40.0-40.5	7.25	152	87.5-88.0		[2]0.0
			29.5-30.0	8.85	2.4	41.0-41.5	7.70	173	98.0-98.5	8.00	2.1
			38.5-39.0	7.50	2.4	Core C-5A			99.5-100.0	7.60	.9
			39.5-40.0	8.50	2.7	47.0-47.5	6.20	3,500,000			
			49.0-49.5		11.0	48.0-48.5	7.60	1,030			
			49.5-50.0	8.85	2.0	49.0-49.5	7.75	84.7			
			69.0-69.5		8.4						
			69.5-70.0		1.4						
			84.0-84.5	8.95	1.7						
			84.5-85.0	8.00	.9						

[1] Depth as measured along angle of slant.

[2] Less than 0.5 micrograms per kilogram, if present.

Table 6.--Analytical results of miscellaneous samples

Sample source	Date sampled	Quantities of organic compounds that elute at the same retention time as the following pesticides (µg/kg) 1/				Remarks
		Dieldrin	Endrin	Heptachlor	Heptachlor epoxide	
			Plant wastes			
Manufacturer	10-05-66	1.2×10^{6}	4.5×10^{6}	0.0	0.0	Still bottoms (liquid)
Do	10-05-66	0.0	0.0	2×10^{8}	3.9×10^{4}	Heptachlor cake (solid)
			Earth materials			
Clay outcrop		0.0	0.0	0.05	0.0	Offsite
Sand outcrop		0.0	0.0	0.09	0.0	Offsite
Topsoil		8.6	21	1600	2.7	Disposal pits

1/ Limit of measurement is 0.01 µg/kg for water and 0.10 µg/kg for sediment

Table 7.--Observation well data for Pesticide Study - Hardeman County, Tenn.

Well No.	Depth below land surface		Elevation above mean sea level		Casing			Screen		
	Drilled (feet)	Finished (feet)	LSD 1/ (feet)	MP 2/ (feet)	Type	Size Length (feet)	Size I. D. 3/ (in.)	Type	Size Length (feet)	Size I. D. 3/ (in.)
A-1	25	21.8	493.2	495.9	Aluminum	16.5	1.5	Teflon	8	1.5
A-2	13	12.9	481.8	482.9	"	10	2.0	"	4	1.5
B-1	15	14.6	481.7	483.1	"	10	2.0	"	6	1.5
B-2	12.5	12.5	472.6	474.1	"	10	2.0	"	4	1.5
C-1	35	27.0	494.9	493.2	"	20	2.0	"	8	1.5
C-3	13	13.0	480.0	481.2	"	10	2.0	"	5	1.5
D-1	20	16.0	485.4	486.2	"	13.3	2.0	"	6	1.5
W-1	122	118.0	513.4	514.4	Steel	120	2.5	Brass	3	1.5
W-2	38	36.6	501.0	502.4	Aluminum	35	2.5	"	3	2.0
W-3	45	41.8	513.3	514.5	"	40	2.5	"	3	2.0

1/ Land surface datum

2/ Measuring point - usually the top of well casing

3/ Inside diameter

Table 8.--Core hole data for Pesticide study - Hardeman County, Tenn.

Core hole number	Elevation of land surface above mean sea level (feet)	Distance from pit (feet)	Inclination from vertical (degrees)	Total depth (feet)	Depth to water (feet)	Depth of core samples below land surface (feet)
A-3	494	30	0	31	dry	3-5.5, 8-10.5, 13.5-15.5, 18.5-20, 23-26, 29.5-31
A-4	496	21	44	45		0-0.5, 25.5-29, 41-45
A-5	496	20	16	101	92	0-0.5, 33-35, 87-90, 98-100.5
B-3	497	16	12	97	92	0-0.5, 94-97
C-2	498	11	48	37	dry	15-17.5, 18-19.5, 24-26.5, 29-31.5, 34-36.5
C-4	495	20	0	85	dry	5.5-8.5, 15.5-18, 27.5-30.5, 38.5, 40.5, 49.0-50.5, 69-70.5, 84.0-85.5.
C-5	498	25	47	51		0-0.5, 31-35, 38-42, 47-51
C-5(a)	498	25	44	50		47-50
D-4	497	18	15	10	91	0-0.5, 34.5-37.5, 85.5-88.5, 98-100.5
W-4	501	370	0	60		0.-0.5, 3-4, 7.5-11, 28.5-30.5, 58-60

Table 9.--Water levels in observation wells near the Pesticide waste disposal site in Hardeman County, Tenn.

Elevation (in feet) of water surface above mean sea level.

Date	A-1[1/]	A-2[1/]	B-1[1/]	B-2[1/]	C-3[1/]	W-1[2/]	W-2[1/]	W-3[1/]
10-14-66	dry	dry	dry	dry	dry	411.47	466.40	472.84
11- 1-66	"	"	"	"	"	411.39	466.35	472.85
12- 7-66	"	"	"	"	"	408.70	465.30	477.17
12-13-66	"	"	"	"	"	411.23	466.22	481.42
1-26-67	474.34	477.88	471.45	463.95	"	411.08	466.15	472.68
2- 1-67	474.36	478.34	472.58	466.07	471.04	411.06	466.12	472.91
2- 8-67	474.28	477.43	472.26	466.31	dry	410.95	466.01	472.93
2-16-67	474.23	476.63	471.92	466.07	"	410.91	466.06	472.72
2-23-67	474.50	478.78	467.52	465.80	"	410.91	466.10	478.07
3- 1-67	473.12	479.27	--	465.89	"	410.95	466.01	472.77
3- 8-67	473.08	479.45	474.55	470.61	468.52	410.83	465.91	472.95
3-16-67	473.23	479.41	474.82	470.64	468.63	410.79	465.96	472.89
3-23-67	473.39	479.45	475.04	470.70	468.70	410.79	466.01	473.08
3-30-67	473.31	477.88	469.10	468.44	469.90	410.89	466.01	472.98
4- 7-67	--	--	468.84	467.60	469.94	410.83	466.13	472.97
4-13-67	473.18	479.39	474.68	470.57	469.46	410.95	466.03	472.96

1/ Perched water zone

2/ Water-table aquifer

Table 10.--Results of hydrologic analysis of core samples from the Pesticide disposal site, Hardeman County, Tenn.

Laboratory sample number	Depth (feet)	Field number	Location	Specific gravity of solids	Dry unit weight (percent)	Centrifuge moisture equivalent (percent)	Specific retention (percent)	Total porosity (percent)	Specific yield (percent)	Coefficient of permeability (gpd per sq ft)
67TN6	12	A	Hardeman County	2.68	1.69	7.1	15.0	36.9	21.9	3
7	12	B	do	2.69	1.70	12.8	23.1	36.8	13.7	3
8	12	C	do	2.68	1.36	9.8	15.2	49.3	34.1	7
9	12	D	Velsicol Farm	2.67	1.52	4.4	9.9	43.1	33.2	68
10	12	E	do	2.67	1.59	4.3	10.3	40.4	30.1	93
11	12	F	do	2.68	1.67	7.6	15.6	37.7	22.1	13
12	12	G	do	2.67	1.56	7.1	13.8	41.6	27.8	13
13	12	H	do	2.67	1.43	2.7	6.8	46.4	39.6	180
14	10	I	do	2.66	1.52	1.3	4.3	42.8	38.5	160
15	10	J	do	2.66	1.82	10.9	21.8	31.6	9.8	0.4[1/]
16	10	K	do	2.66	1.61	8.0	15.6	39.5	23.9	22[1/]
17	10	L	do	2.68	1.60	13.9	23.1	40.3	17.2	3
18	10	M	do	2.66	1.51	12.3	19.7	43.2	23.5	57

1/ Repacked sample

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